Controls of food chain length in stream ecosystems

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What is food chain length?

- Number of transfers of ‘energy’ from ‘bottom’ of food web to ‘top’
  - ‘Energy’ = organic carbon
  - ‘Bottom’ = weighted average of aquatic and terrestrial sources of organic C
  - ‘Top’ = biggest, meanest, toughest predator out there

Photo Credit: Suthep Kritsanavarin, US Newswire

Why is FCL important?

- Contaminants accumulate with trophic transfers too
- FCL can me manipulated to control algal blooms

What determines FCL?

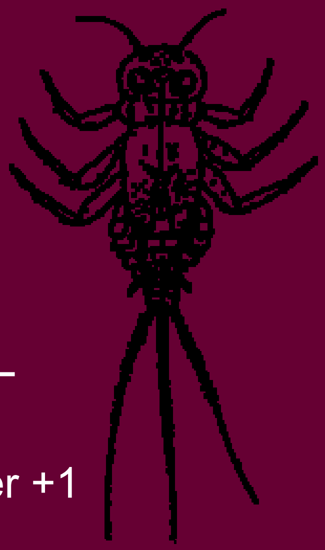
- Resource supply (productivity)
  - Trophic transfer efficiencies are low (~5-20%)
    - In either case, 99% energy gone in 3 transfers
  - Larger resource supply → longer food chains (Elton 1926, Lindeman 1942)
- Ecosystem size
  - "Productive space" → longer food chains (Schoener 1989)
  - Just space → longer food chains (Post et al. 2000)
- Environmental Stability or Disturbance
  - Long term *in*stability → shorter food chains (Pimm 1982)
  - Short term disturbances → longer food chains (Power 1995)

What determines stream FCL?

- H1: Disturbance is paramount
  - May shorten (low flow) or lengthen (high flow) *realized* FCL
- H2: FCL increases with ecosystem size—within a given disturbance regime
  - Bigger pond = bigger fish
- H3: Resource availability (RA) will have a very minimal effect on FCL once the effects of disturbance and ecosystem size are removed
  - RA measured as GPP & ER via 2 station open channel methods
  - GPP more strongly related to FCL than ER

How do we measure FCL?

- Stable isotopes ($\delta^{15}N$ and $\delta^{13}C$)
  - You are what you eat + 3.4‰ in $\delta^{15}N$
    - Consumers are enriched by ~3.4 ‰ in $\delta^{15}N$ compared to their 'average' prey item
    - $\therefore$ $\delta^{15}N$ is a trophic tracer
  - You are what you eat in $\delta^{13}C$ (+ <0.5 ‰)
    - Algal and terrestrial organic C *can* differ in $\delta^{13}C$
    - $\therefore$ $\delta^{13}C$ can be used as a C-source tracer
  - Mixing models using both isotopes allow us to estimate FCL with up to 3 distinct C sources
    - FCL = $\delta^{15}N$ Top consumer - $\delta^{15}N$ Omnivorous Basal Consumer +1
      - Following Post 2002



How do we measure independent variables?

- Disturbance: New method using time series of average daily discharge measurements
- Ecosystem Size: cross sectional area (CSA) or watershed area (WA)
- Resource availability: GPP and ER from 2-station open channel measurements of metabolism

Where do we get the data?

- Published data
  - Lotic Intersite Nitrogen eXperiment (LINX I & II)
    - 8-12 sites in NA, thanks to Pat Mulholland & Jen Tank
  - STROUD
    - 8-10 sites in Hudson River drainage thanks to Dave Arscott
  - Problems with published data
    - Not all same methods
    - Not all variables available for each stream
    - Missing some desired range of variation in some variables . . . . Mid-sized streams and large rivers
- Primary data collection
  - Arizona & New Mexico (8 sites)
  - Minnesota (8-10 sites)
  - New York (a few large rivers)

What I am going to show you today . . .

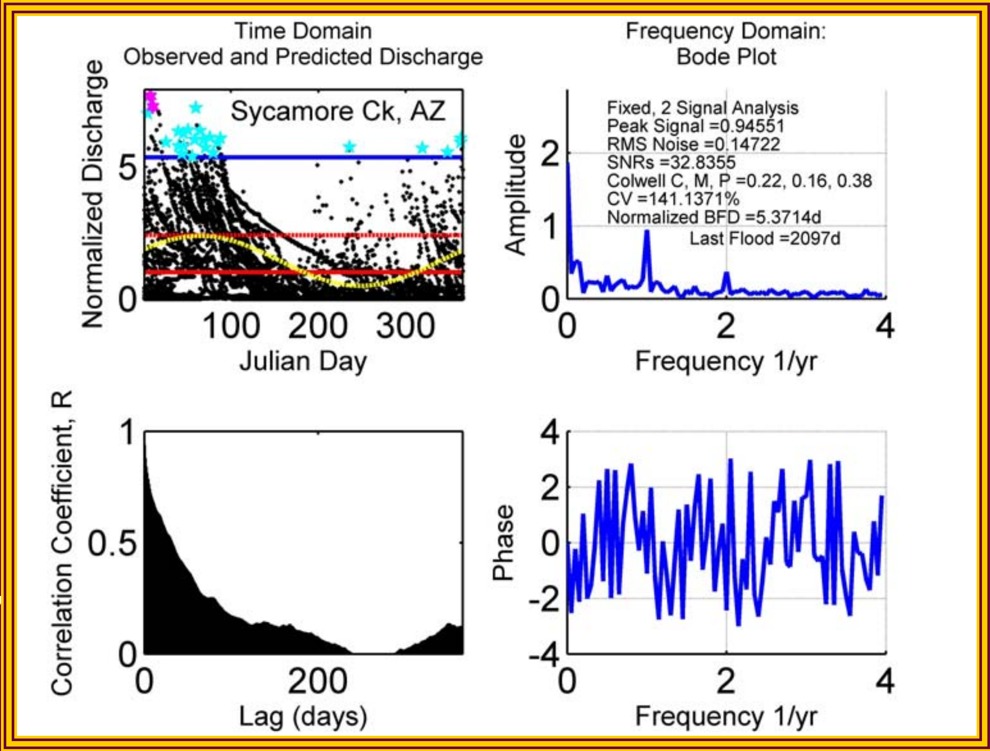
- How we measure daily, seasonal and inter-annual variation in discharge
  - New use of old technique: *Fourier transform*
  - Environmental stress, stochasticity, noise color and disturbance
- *Univariate* relationships between the three classes of independent variables and FCL
  - Tantalizing but not complete
  - More data needed for complete multiple regression analysis

Fourier analysis of NWIS Web daily discharge data

- Fourier transform converts data from time to frequency domain

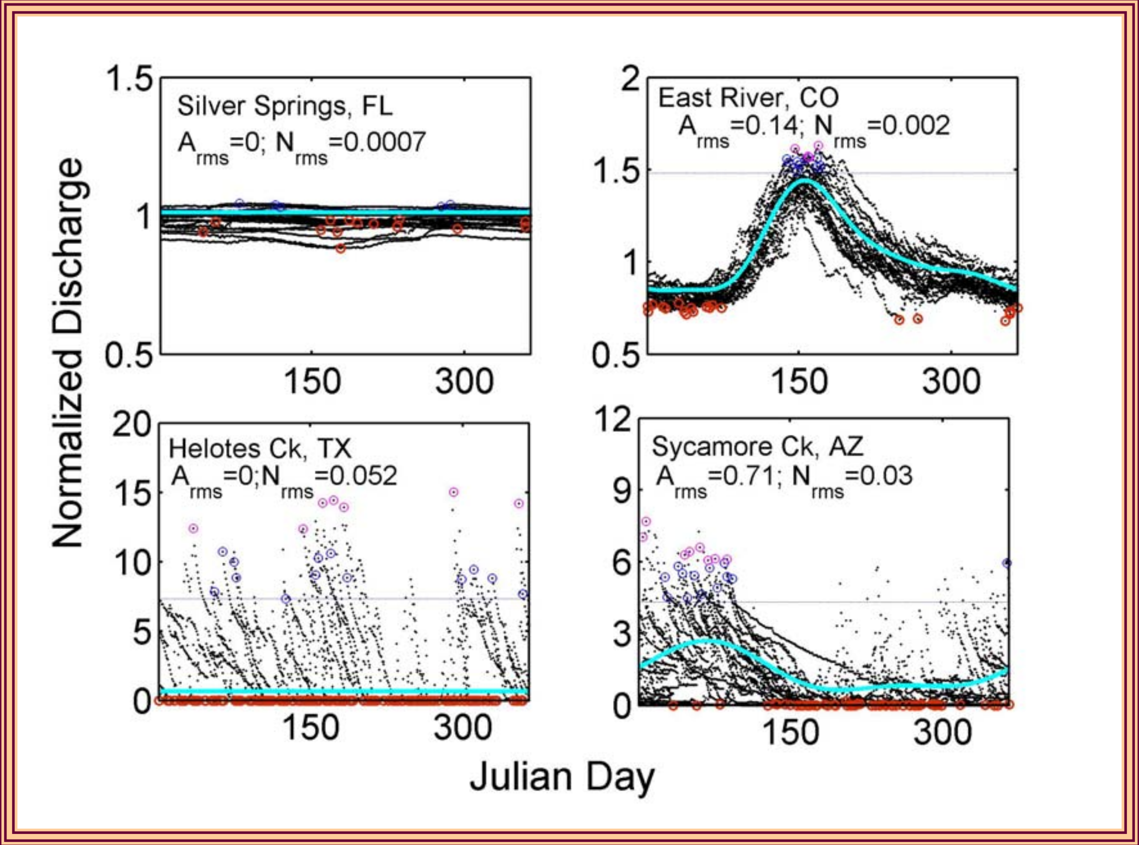
$$D(k) = T^{-1/2} \sum_{t=0}^{T-1} d_t \exp\{-2\pi i v_k t\}$$

- Decomposes seasonal and inter-annual variation in frequency domain
  - Seasonal variation = 'signal'
  - Inter-annual variation = 'noise'



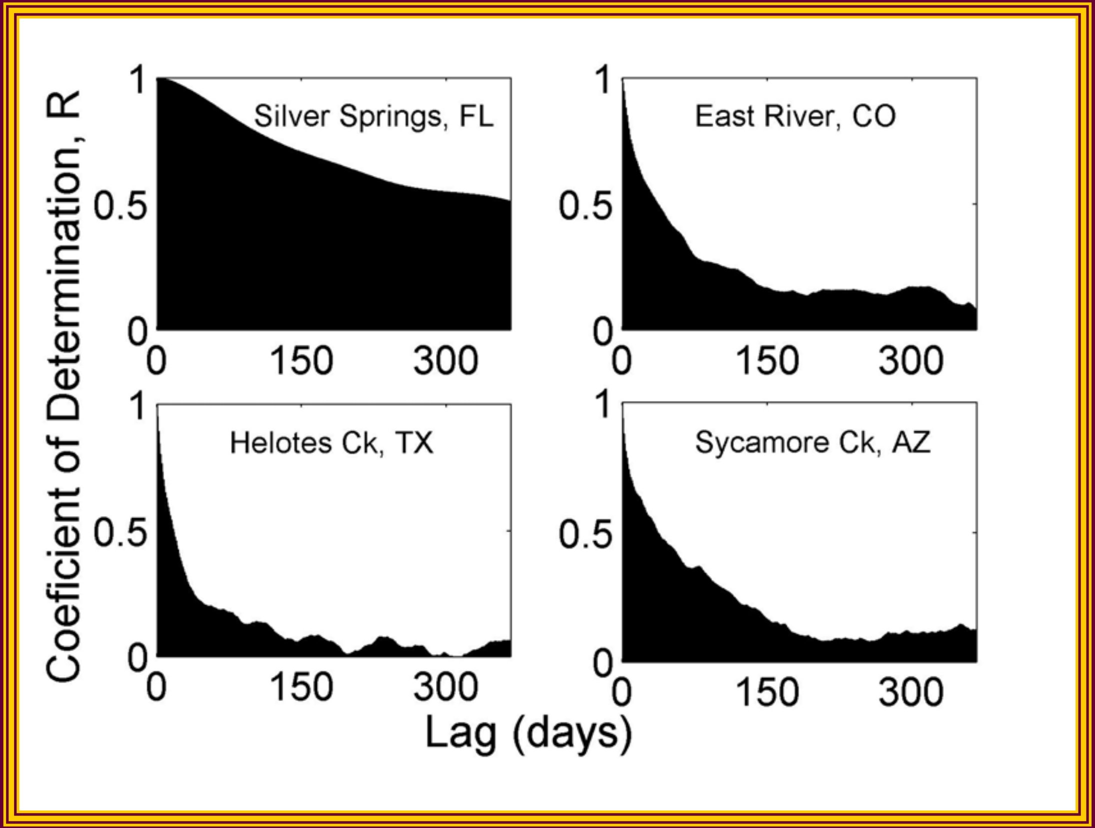
Example: Seasonal and inter-annual variation among 4 US streams

High ← Inter-annual variation → Low



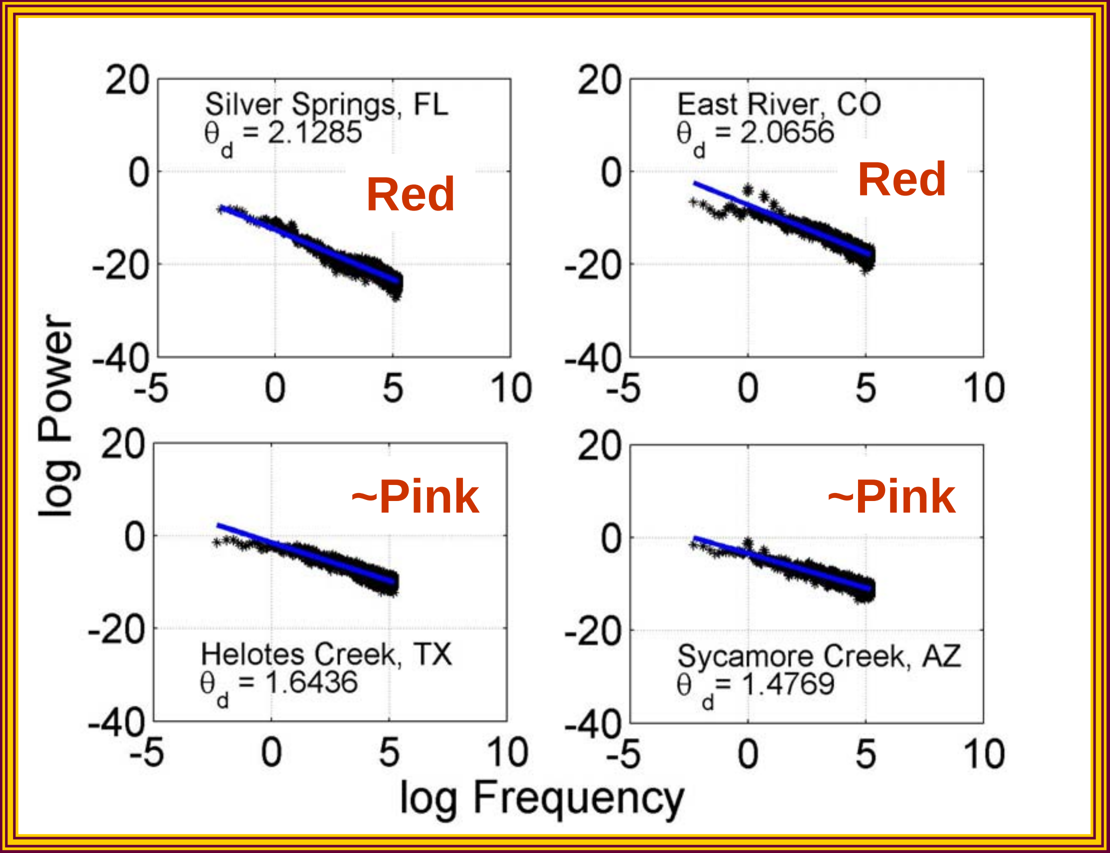
Low ← Seasonality → High

Correlograms: storage of atmospheric inputs



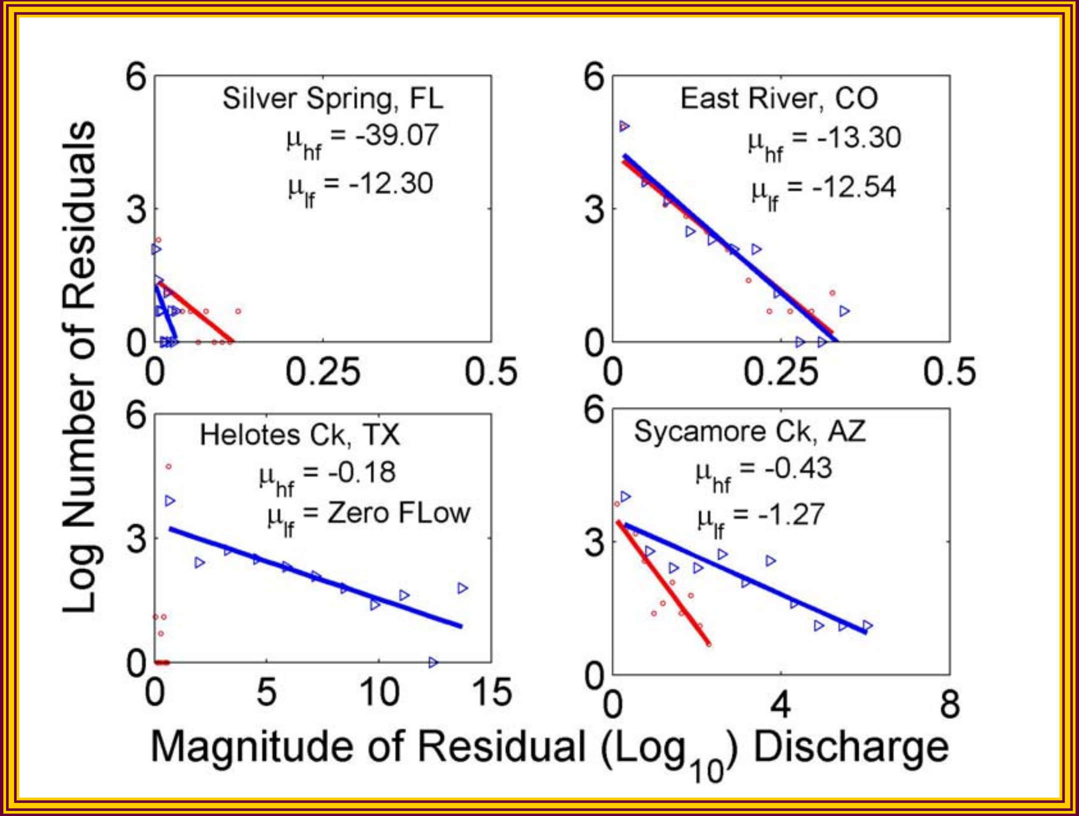
- More black = longer storage of rain events
- Slow vs. flashy release of hydrologic inputs

Noise color: hydrologic storage and flashiness in stream hydrographs



- White Noise, θ_d~0
  - Flashy, no 'storage'
- Pink Noise, θ_d~1
  - A little short-term term 'storage'
- Red Noise, θ_d~2
  - More short term 'storage'
- Black Noise, θ_d~3
  - Lots of short-term 'storage'

High- and low-flow intensity



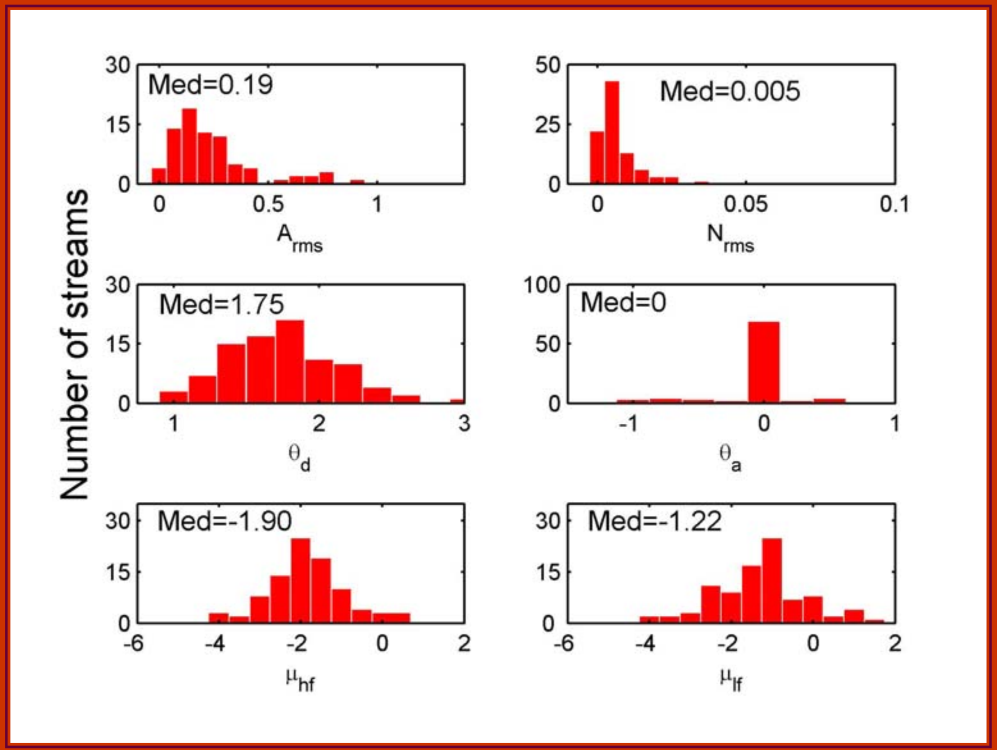
- Red line = Low flow
- Blue line = high flow

- μ is the slope of each line
- The flatter the slope, the more intense the low- or high-flow regime
  - i.e., lots of large residual values

Summary of discharge metrics

- Seasonality, A_{rms}
  - Equivalent to ‘Environmental Stress’ (Menge & Sutherland 1986)
- Inter-annual variation, N_{rms}
  - Equivalent to ‘Environmental Stochasticity’
- Signal to Noise Ratio (SNR)
  - Ratio of stress/stochasticity
- Daily-scale hydrologic storage
  - Equivalent to ‘Noise Color’ on daily time scale
- High- & Low-flow intensity
  - Integrated measure of disturbance that includes magnitude and frequency
  - Allows for analysis of low- and high-flow disturbance

Distribution of flow metrics in data analyzed by Poff & Ward (1988)

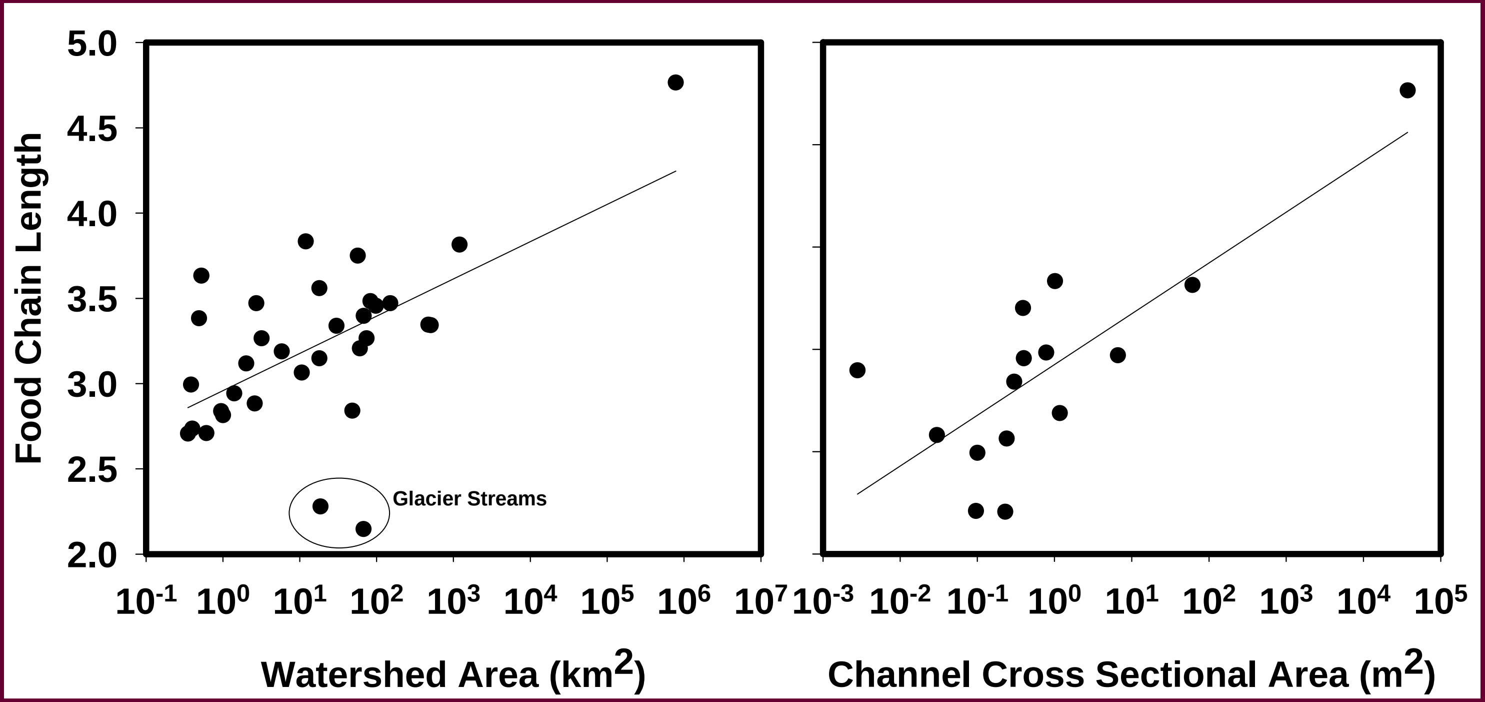


- Many are normally distributed
- Some patterns in central tendencies are compelling
  - Noise color is nearly red on a daily scale, but white on an annual scale
  - High and low-flow disturbance is typically low (i.e., slopes > -1 are rare)

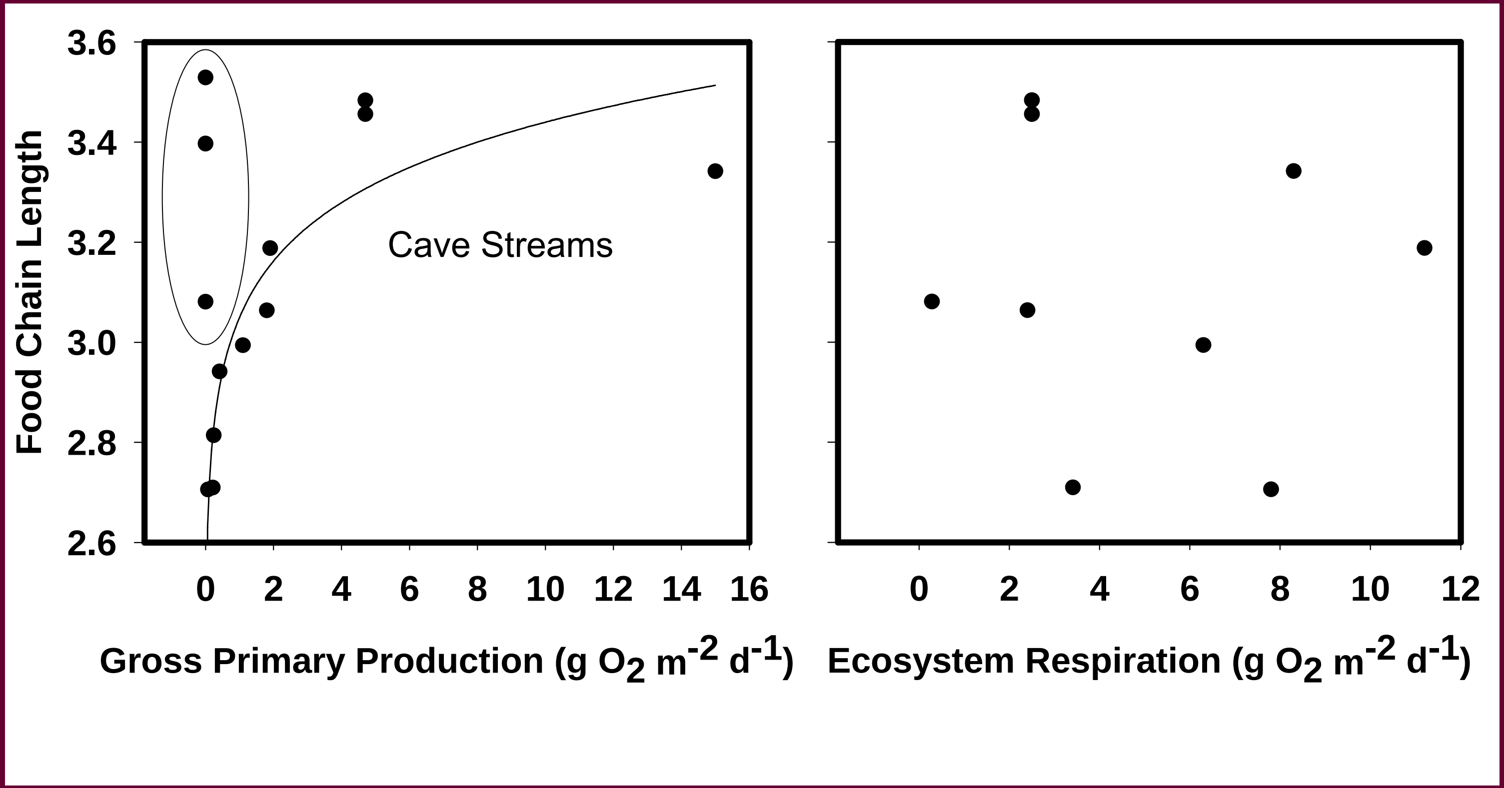
Controls on FCL in streams

- Ecosystem size
  - Here we look at WA and CSA
- Resource availability
  - Here we look at GPP and ER
- Disturbance
  - Here we just SPECULATE about SNR, μ_{hf} and μ_{lf}

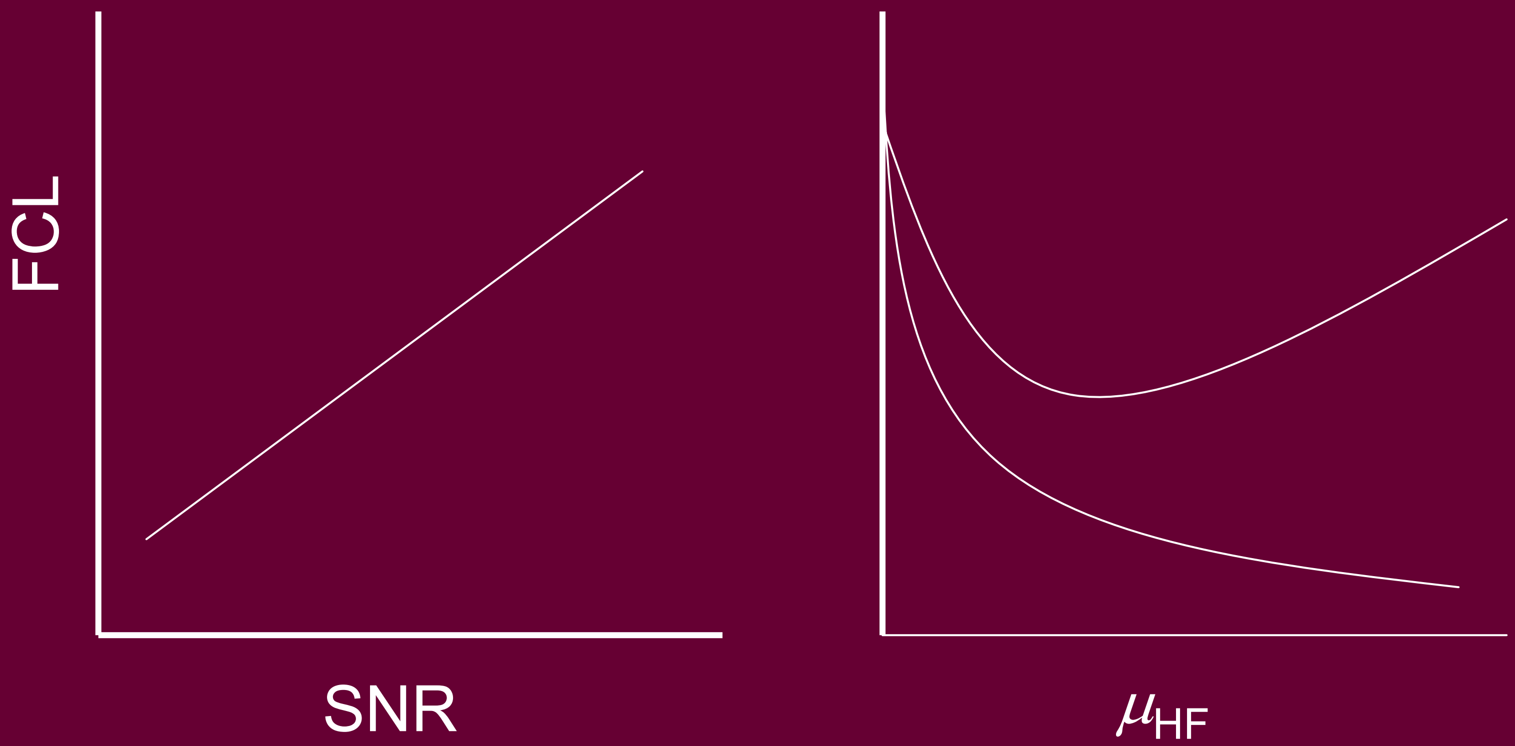
Ecosystem size



Resource availability



Disturbance (some speculation)



Summary

- Fourier methods provide compelling way to classify some biologically relevant properties of daily and annual variation in discharge
- Some tantalizing correlations between other independent variables and FCL
  - Positive effect of WA & CSA on FCL (similar to Post et al. 2001)
  - Saturating positive effect of GPP on FCL
    - No effect of ER on FCL (so far)
  - Positive effects of GPP and Size support ‘Productive Space’ hypothesis
- Work in progress
  - Big question: are the observed univariate effects contingent on disturbance
    - Multivariate analyses
      - Including flow metrics
      - Structural equation modeling to alleviate collinearity
  - Furiously filling in data gaps with primary measurements

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How do we measure FCL?

- Realized vs. Functional FCL
  - Isotopes → realized FCL based on ‘assimilation’ of C from all prey items
  - Experiments → functional FCL based on measured effects of top predators on basal resources